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Flight Mechanics Technical Memorandum 456

# THE USE OF ULTRASONICS FOR OLEO COMPRESSION MEASUREMENTS ON A S-70B-2 (SEAHAWK) HELICOPTER

by

S. DUTTON
S. WALTER



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## SUMMARY

*Dynamic measurements were conducted to acquire data for the development of a mathematical model of the undercarriage of a S-70B-2 (Seahawk) helicopter. The principal measuring instrumentation consisted of LVDT's and ultrasonic transducers. This memorandum discusses a Ranging Ultrasonic Transducer which was developed to overcome the inherent and excessive recovery time delay of the ultrasonic transducers when subjected to out-of-range distance operations during the flight trials.*



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## Contents

## 1.0 INTRODUCTION

A mathematical model of the undercarriage of a Seahawk helicopter is being developed at ARL (Ref 1). In order to validate this model Oleo/Tyre Deflection Trials on the helicopter were performed at Naval Air Station Nowra in November 1989 and in May 1991. Both main wheels and the tail wheel undercarriage were instrumented on both occasions to measure oleo extension/compression and tyre deflection. Two types of transducers were used, an ultrasonic type to measure the fuselage to ground distance and Linear Variable Differential Transformers (LVDT's) to measure the extension/compression of the oleos (Ref 2). The outputs from these transducers, along with data from an onboard motion platform, were recorded on an ARL designed and constructed Versatile Data Acquisition and Replay (VADAR) system (Ref 3).

This memorandum addresses the difficulties experienced in the use of the Honeywell Ultrasonic Transducers (UST), in that a recovery time delay of typically 450ms occurs when the reflected ultrasonic beam is first received by the transducer. This normally occurs when the UST is operated outside the specified distance range of the transducer. The recovery time problem was most critical during landing as valuable touchdown data could be lost because of sudden changes in aircraft attitude or altitude. Since the UST is fully sealed it is not practical for the user to modify the recovery time response. Therefore, to overcome this problem, Ranging Ultrasonic Transducers (RUST's) were developed by the Instrumentation and Trials Group at ARL which were electrically connected to the commercial transducers to minimise this recovery time delay. This memorandum also describes the operation and use of the ranging ultrasonic transducers and provides general information on the use of ultrasonic transducers for measuring helicopter undercarriage deflections and ground proximity.

## 2.0 BACKGROUND

The primary objective of the November 1989 flight trail with the Seahawk was to determine the ground clearance of the under fuselage mounted radome during various landing conditions. Four UST's were equally positioned around the circumference of the radome where it attaches to the fuselage. The HOLD line of the UST, which when asserted holds the last remaining data until the signal is negated allowing the UST to operate normally again, was electrically connected to the "weight on wheels" switch located on the front oleo which is activated when the wheel touches the ground. The four UST's were enabled when the wheel touched the ground and all UST's were then within their specified operating range of 300 to 1800mm. Subsequent signals recorded by VADAR from the UST's provided a measure of the reducing distance to the ground at the four positions (fore and aft, port and starboard) around the radome during the remainder of the landing. Likewise, takeoff distances were also recorded until the wheel left ground contact.

The secondary objective related to fitting transducers to the undercarriage of the helicopter to acquire data for use in developing a computer model of the undercarriage.

Because the aircraft pre landing attitudes were so variable, the distance to the ground from an UST was often outside the specified 1800mm maximum range when the "weight on wheels" switch was actuated. For this reason all downward viewing UST's were controlled by individual RUST's, during the November 1989 flying trial and later when operating aboard RAN ships during First of Class Flight Trials (FOCFT).

Useful data were acquired for the computer model during the series of landings and takeoffs but there were too many uncontrolled variables in the flight trial environment to fully validate the undercarriage model. Although the VADAR motion platform provided transducer signals of roll and pitch attitude plus three axis rates and accelerations every landing was different. Some of the uncontrolled variables were rate of descent, landing attitudes, pilot input controls and wind effects.

In May 1991 a series of non flying measurements was obtained under more controlled conditions where it was practical to fit ground-actuated LVDT's to measure tyre deflections directly and more accurately (Ref 2). To determine the step response of the undercarriage, landings were simulated using a mobile crane to raise the helicopter to pre-selected heights then, with VADAR in the record mode, allowing the aircraft to free-fall by switching an electrically operated quick release cable hook.

Under field conditions the LVDT provided more accurate and repeatable measurements than a UST. However, for distance measurement between two moving sections the LVDT needs to be attached to one section and the sliding core of the LVDT to the other section. This requirement was easily met for measurement of the compression and expansion movement of the two front oleos for both the flying and non flying conditions. The UST has a definite practical advantage over the LVDT by being able to measure the displacement within a specified range without physical contact between the two moving sections. For the flying trials, the UST's provided a convenient non-contact technique to separately measure the distance changes of the fuselage, tail oleo and the tyres with respect to a common ground (tarmac or ship deck) reference. For the non-flying trials it became practical to attach LVDTs at various positions on the fuselage and wheels and provide extended spring-loaded probes to ensure reliable contact for the sliding cores.

## 3.0 TESTING OF ULTRASONIC DISPLACEMENT TRANSDUCERS

An experimental rig was utilised to evaluate the UST transducers. The transducer was mounted in a fixed position and a target plate, representing the ground, was allowed to free-fall from various heights both inside and outside of the operating range (Fig. 1). The response time to produce a valid result could then be calculated. When the target was dropped from outside the operating range the transducer required 450ms to produce valid data after coming within range when viewing the analogue output signal on a storage oscilloscope. This delay also occurs within the operating range if the target plate is angled with respect to the ultrasonic beam, so that the reflected signal intensity is below the threshold of the receiver. The cone angle for the transmitter was specified as 10 degrees.

A more repeatable evaluation of the UST was performed by attaching the target plate to the sliding portion of a variable stroke shaping machine. Also, with a LVDT attached and relative sensitivities adjusted on a dual beam oscilloscope, the analogue signals from the UST and the LVDT were identical up to the maximum stroke speed of 180 times/minute (3Hz).

**4.0 AIRCRAFT TRANSDUCER FIT**

To measure the compression/extension of the oleos, LVDT's were fitted between the body of the oleos and the lower end of a support strut on both front undercarriages (Figs 2&3). UST's were positioned to measure the height from the ground to their mounting position on the helicopter fuselage. Knowing both the oleo extension and the distance the UST was from the ground allowed the compression of the tyre to be calculated by taking the difference between the two results.

The clearance around the tail wheel assembly restricted the mounting and operation of a LVDT during flight trials so two UST's were fitted (Figs 4&5). The first pointed downwards to measure the distance from the common mount to the ground, in the same manner as those mounted at the main oleo. The second UST pointed upwards to measure the distance from the mount to the base of the fuselage (in place of the LVDT's used for the main oleo measurements). During a landing the helicopter usually approached (from outside the 1800mm useable range of the UST) with a descent rate high enough to compress the oleo considerably during the UST 450ms recovery time delay and so cause a loss of valuable data.

In order to shorten the recovery time delay, after the target comes within range, two techniques were tried. Firstly power was applied to the device only when the target was in range. This proved to be unacceptable due to a 1 second turn-on delay. The second method involved enabling the HOLD pin on the transducer to retain the analogue signal level. HOLD is enabled when a voltage of less than 3.5V is applied. When the HOLD is raised above 10V the UST operates normally. If the hold function is applied whilst the target is out of range and removed when it comes into range the transducer recovered after a delay of 70ms which was considered acceptable. However the HOLD signal has to be removed at least 70ms prior to any of the aircraft wheels touching ground, for valid data to be acquired. The option was to utilise another form of ultrasonic transducer (RUST) to provide the required gating for the UST.

The RUST asserts the HOLD state to the UST when the measuring distance during a landing is outside its normal operating range of 1800mm and removes the HOLD state when the ground is within range of the UST.

As the helicopter approaches the ground the wheels may be at different relative heights because of fuselage roll and pitch angles. Also, the preferred landing technique was to land tail wheel first followed by the port and finally the starboard wheel. Thus for each transducer to operate within the specified range required independent enabling. Three RUSTs were therefore used, one for each of the three downward facing UST's. The UST assigned to measure the distance from the rear oleo up to the fuselage always remained within range and therefore did not require gating via a RUST.

The UST's selected to measure the dynamic distances from the ground at each of the three reference positions on the helicopter fuselage were HONEYWELL 941-C2T-2D-1C0. These were chosen because of good accuracy, measured at approximately 1% when operating within the range 300-1800mm. The transducer has a user selectable operating range depending on the sensitivity chosen. For the undercarriage application the maximum operating range of 300-1800mm was selected setting the sensitivity at 5mV/mm. Each UST is factory set to pulse 30 times/second to provide an analogue signal output.

## 5.0 RANGING ULTRASONIC TRANSDUCER CIRCUIT DESCRIPTION

The RUST's were designed to approximately measure the range to the target (the ground) and control the HOLD signal to the UST.

The RUST circuitry is split into three different sections:

1. Transmitter.
2. Receiver.
3. In-Range Detector.

### 5.1 Transmitter

A 5 millisec burst at 40kHz repeated at a pulse repetition rate of 55Hz is produced by combining the outputs of the two halves of an LM556 oscillator configured as an astable multivibrator (Figs 6 & 7). The ultrasonic transmitter, type SCS-401, is typically pulsed ON for 5ms with a 40kHz square wave applied and then OFF for 8ms. These times allow a pulse to traverse more than 4m (2m down and then 2m back up) before another pulse is transmitted, using 300 m/sec as the speed of sound.

This signal is passed through a high pass RC filter (to remove the DC component) then amplified. The non-inverting Op-Amp (LM301) provides a gain of 7.8 that produces an output signal that switches between ±15V. Because of distortion in the Op-Amp the output waveform is not square and is further degraded when the amplifier output is loaded by the piezoelectric transducer which acts as an ultrasonic transmitter. This distorted signal is sufficient to drive the transmitter since it contains the fundamental sinusoidal frequency of 40kHz.

### 5.2 Receiver

A load resistor of 100K was chosen for the receiver, type SCM-401, to provide maximum sensitivity. The received signal passes through a two-stage amplifier with the first stage having a fixed gain of 31 and the second stage having a variable gain of between 8 and 20. Both stages are non-inverting LM301's which feed a diode clipper which removes the negative component of the signal as required by the Phase Locked Loop (PLL). The PLL is designed to free run at 40kHz and lock onto incoming signals in the frequency range 38-43kHz. The PLL allows the input signal to be discriminated from a large amount of noise which is present in the signal. The PLL produces a series of lock pulses. However, spurious signals occur due to the digital comparator network used in the PLL which compares a square wave with the incoming signal.

The lock signal is filtered and applied to a retriggerable monostable circuit which gates out and so removes signals of small duration. The length of signals this circuit removes is variable and is currently set at 2ms to discriminate from a valid reflected burst signal which is typically of 5ms duration. Note that this circuit introduces a delay of the same duration as the pulse length it is set to remove. The resulting pulse train is then applied to the In-Range Detector.

### 5.3 In-Range Detector

The receive pulse is compared with the transmitted pulse (Fig. 6). For an in-range signal the received pulse must lie within a predetermined time WINDOW, before the next pulse is transmitted. This WINDOW is provided by an LM556 monostable triggered by the 55Hz oscillator and has a variable output pulse length (Fig. 7). The received pulse must lie within the WINDOW including the fixed delay introduced by ignoring short duration pulses. The comparison between pulses is performed by two latches. If the received signals are within range the output of the "a" latch (Fig. 6) is a logic one. The inversion of the monostable output clocks the first D latch to provide the HOLD signal. The received pulse clocks the second D latch which is feedback connected to the data pin of the first latch. As the WINDOW closes (monostable output becomes LOW) it clears the second latch and clocks the first latch at the same time. Due to propagation delays, within the second latch, the logic state is still present on the data pin of the first latch as it is clocked. The output of the first latch remains high as long as the device is within range. By adjusting the size of the WINDOW the circuit can enable the UST at varying heights and is currently adjusted to release the HOLD on an UST at a height of 1m. Although the output of the CMOS latch meets the specification for the HOLD pin of the UST, the output is applied to the HOLD pin through a comparator which can source/sink more current than the latch and effectively buffers the transducer.

## 6.0 PERFORMANCE

In the laboratory there were negligible differences between the calibrated static and dynamic distance measurements using the LVDTs and the USTs. However, in a hangar while the aircraft was being jacked for static calibration the USTs occasionally produced seemingly inconsistent and unexplainable measurements. No noticeable deterioration occurred in measurement reliability when the USTs were exposed to rotor down wash, noise and temperature signatures during landing or takeoff flying operations. More consistent results were obtained from a wet concrete or flat metal surface rather than from a dry or asphalt surface. During these comparisons the intensity of the reflected signal was adequate as shown by the UST receiver indicator.

Figure 8 shows the outputs of both the UST and its controlling RUST whilst the aircraft was landing. These results were obtained from the FOCFT with a S-70B-2 operating aboard HMAS Adelaide (an FFG 7) during April 1990. It can be seen that while the RUST signal is low (during the first 100 samples), thus holding the UST, the output signal is constant at 5V which would be the last value before the RUST went out of range. The RUST signal oscillates (near the 100 sample mark), probably due to spurious reflections caused by the changing attitude of the helicopter, however these were not of sufficient duration to release the HOLD and allow the UST operate normally. Once the RUST was finally in-range and removed the HOLD from the UST (at approximately the 125 sample position) there was about 80ms delay before the UST started to produce valid data. The remainder of the graph shows the RUST permanently in range with the UST producing valid data (at approximately the 200 sample position the tailwheel compressed on contact with the ground then overshot before settling to a static deflection).

## 7.0 CONCLUSIONS

The RUST circuit was used on several flight trials including the Radome Clearance and a FOCFT and performed well. The UST's also performed well but were considered to be unreliable as several inexplicably failed in service and being a sealed unit were not field repairable.

A possible extension of the RUST development would be to provide an analogue output proportional to distance, similar to the UST, but with a much shorter recovery time delay from an out of range situation.

## ACKNOWLEDGMENTS

Many people were involved in both the testing of the UST and subsequent design and implementation of the RUST both in the laboratory and during trials but the authors would like to particularly thank A.J. Leslie for her help in designing of the circuit boards and constructing the RUST units.

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Aeronautical Research Laboratory Letter Report to Aircraft Maintenance and Flight Trials Unit (AMAFTU ) RAN. August 1989.

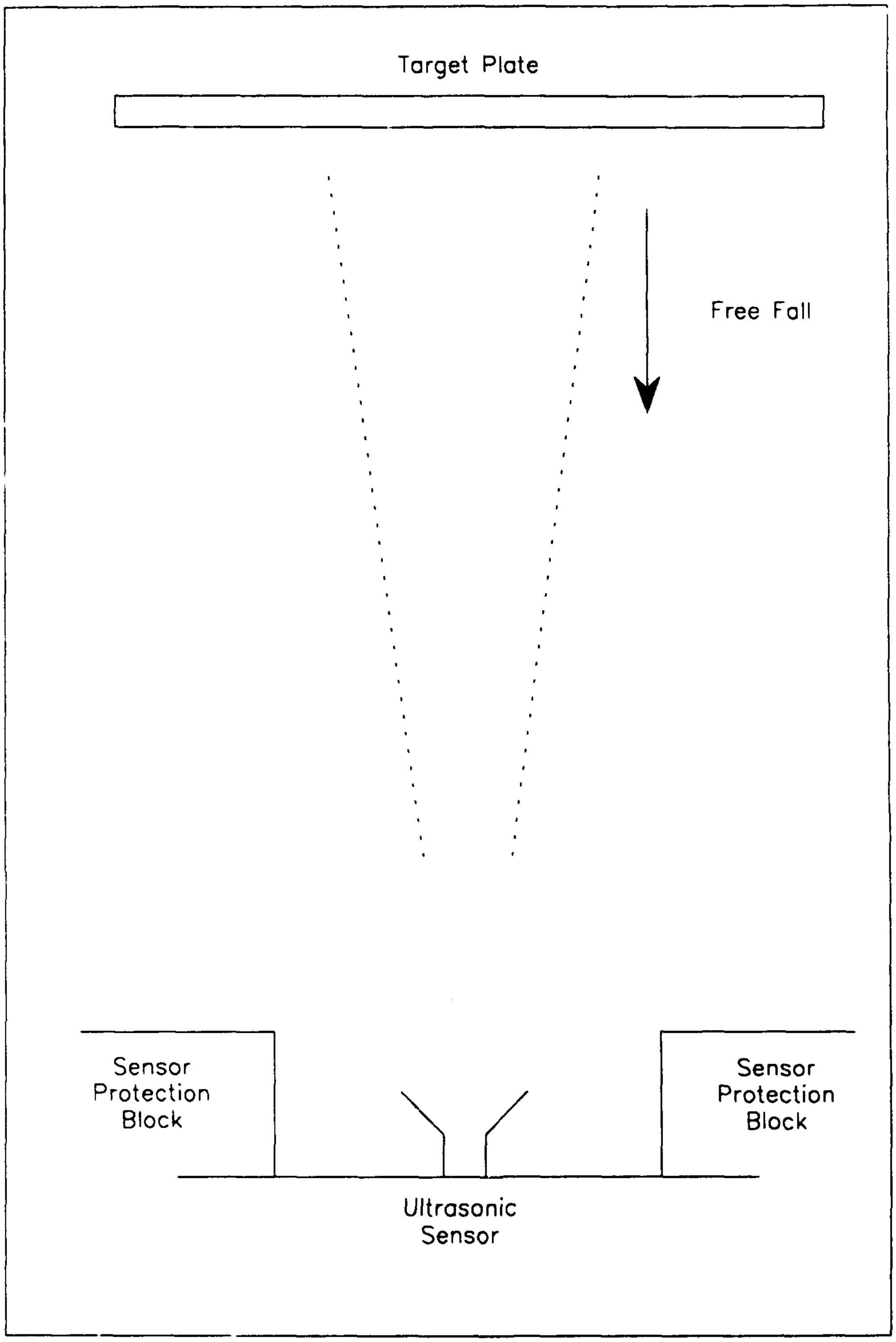


**Figure 1. Arrangement for testing ultrasonic transducer**

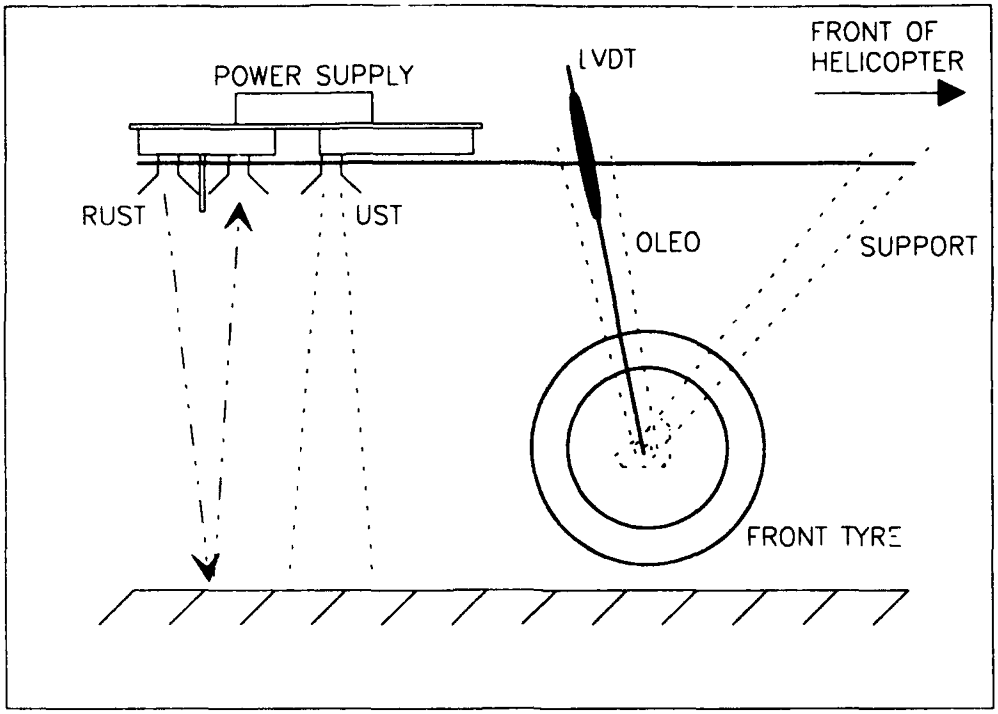


**Figure 2. Instrumentation fit for front undercarriage of Seahawk**

**Figure 3 Front Undercarriage with LVDT, UST & Rust Fitted**

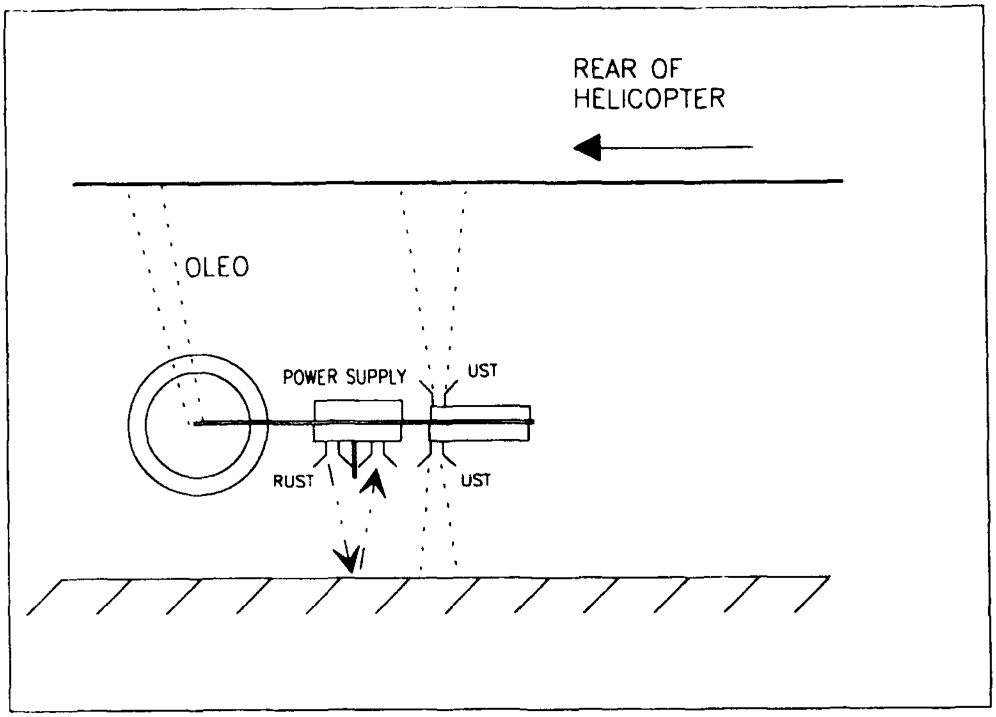


**Figure 4. Instrumentation fit for rear undercarriage of Seahawk**

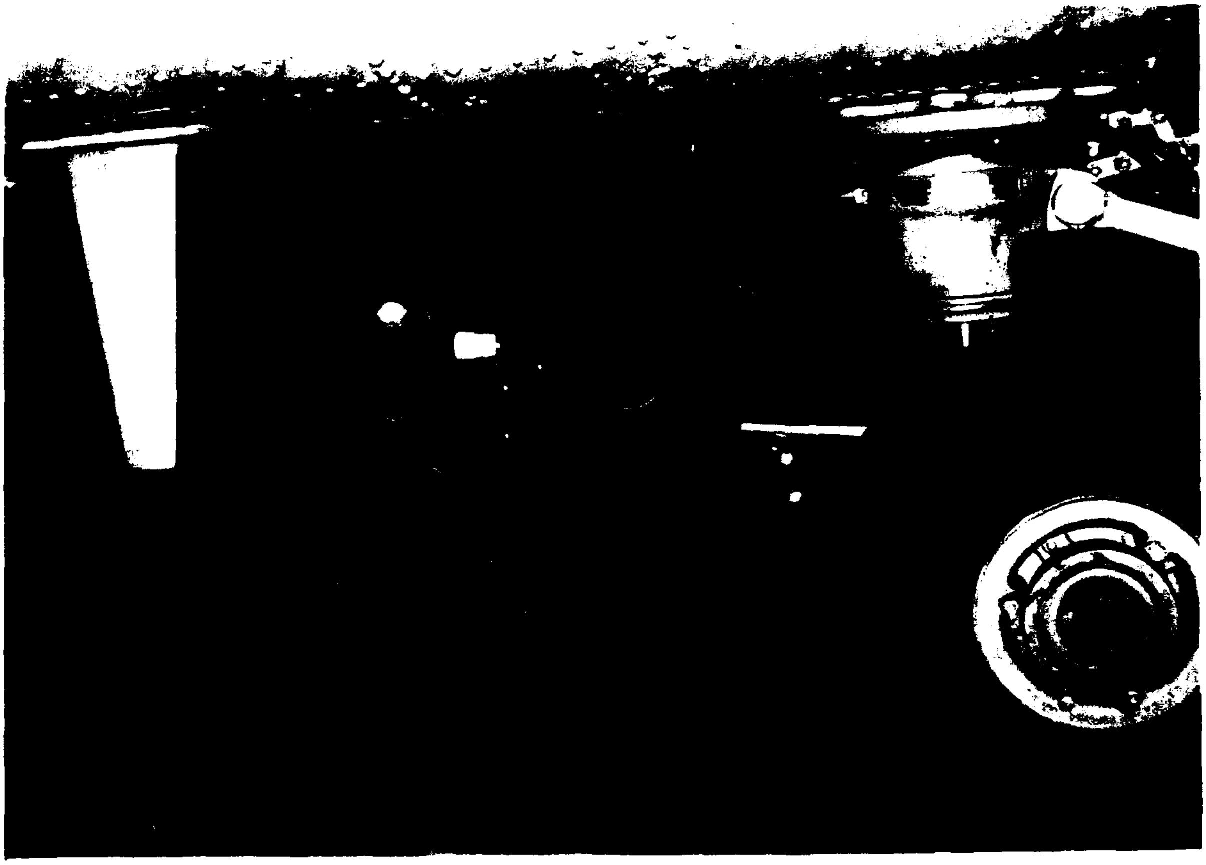

**Figure 5. Rear Undercarriage with UST & Rust Fitted**

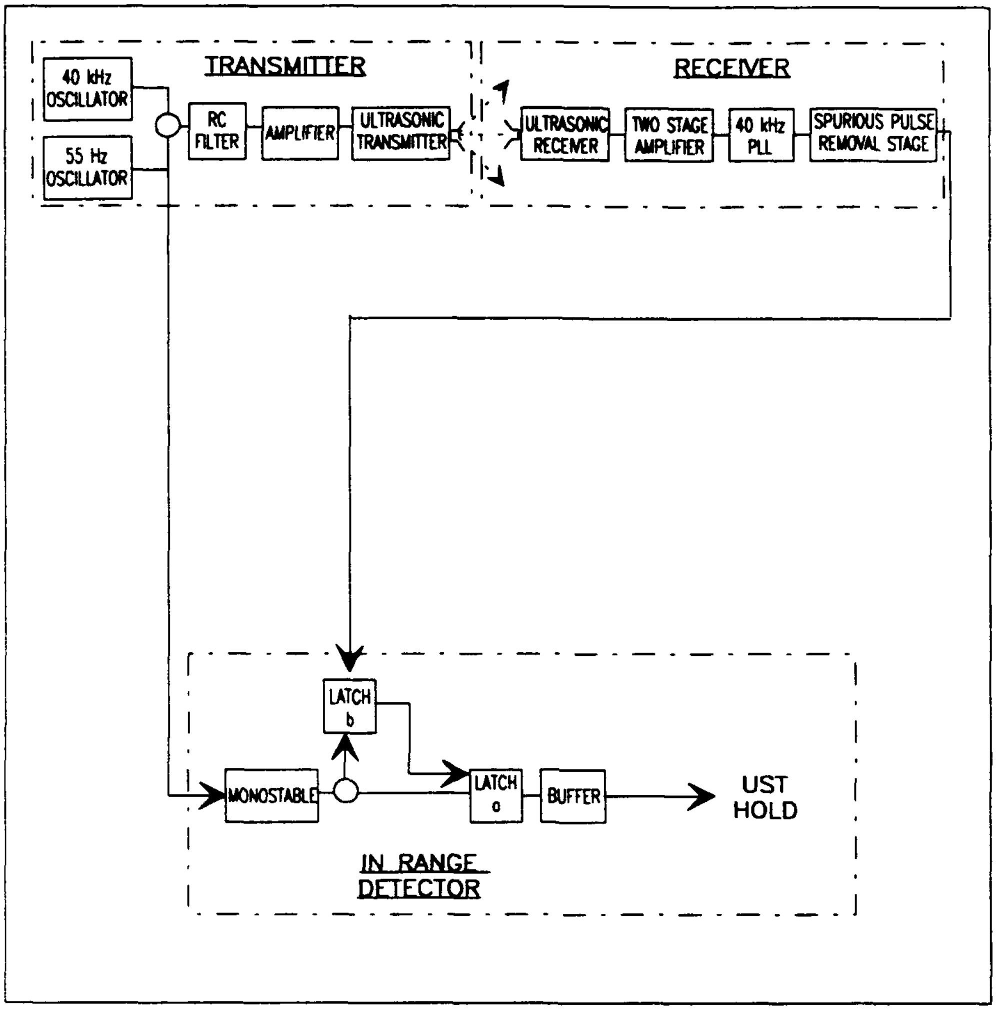


**Figure 6. RUST - Block Diagram**

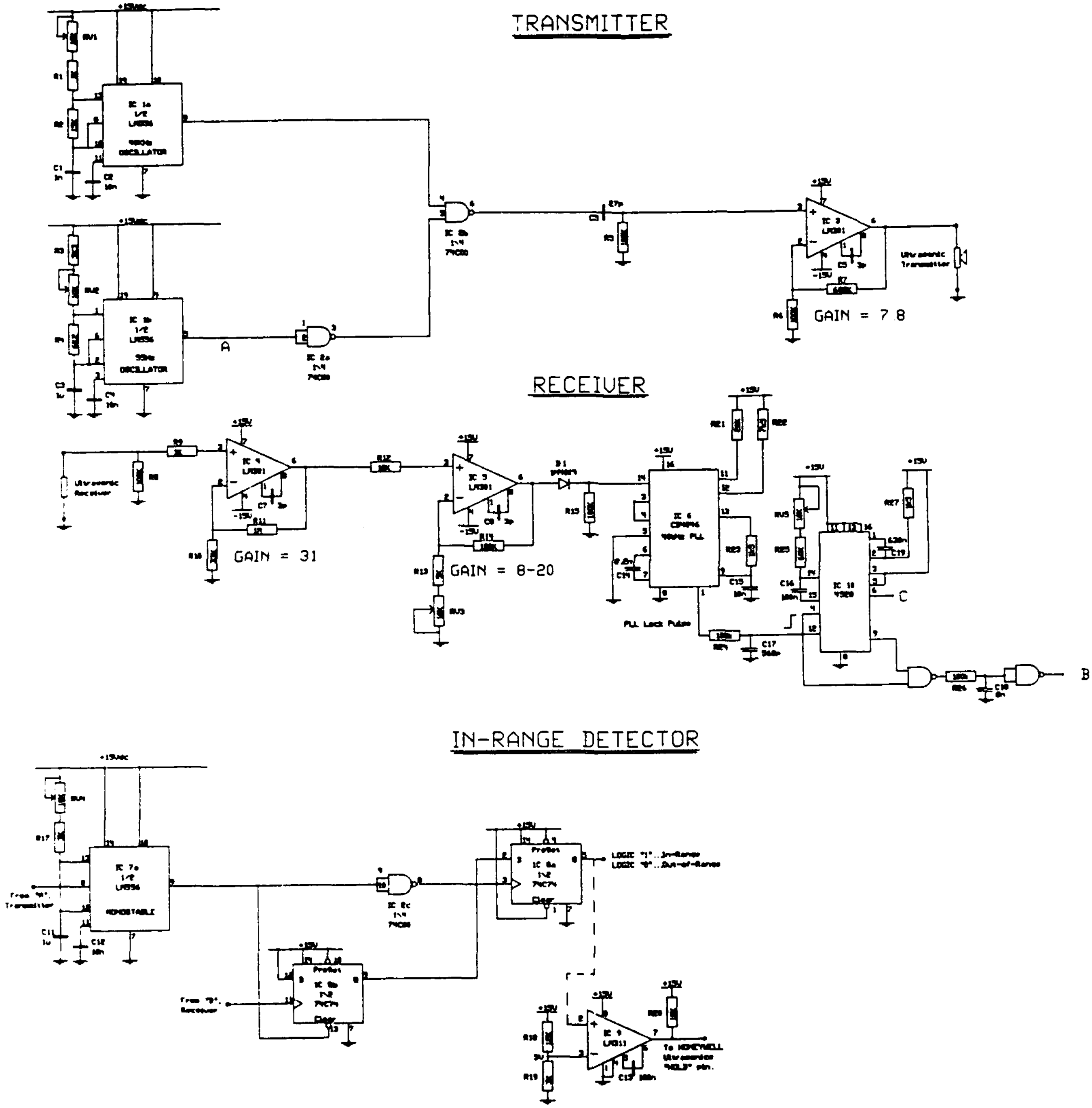


**Figure 7 Circuit Diagram for RUST**

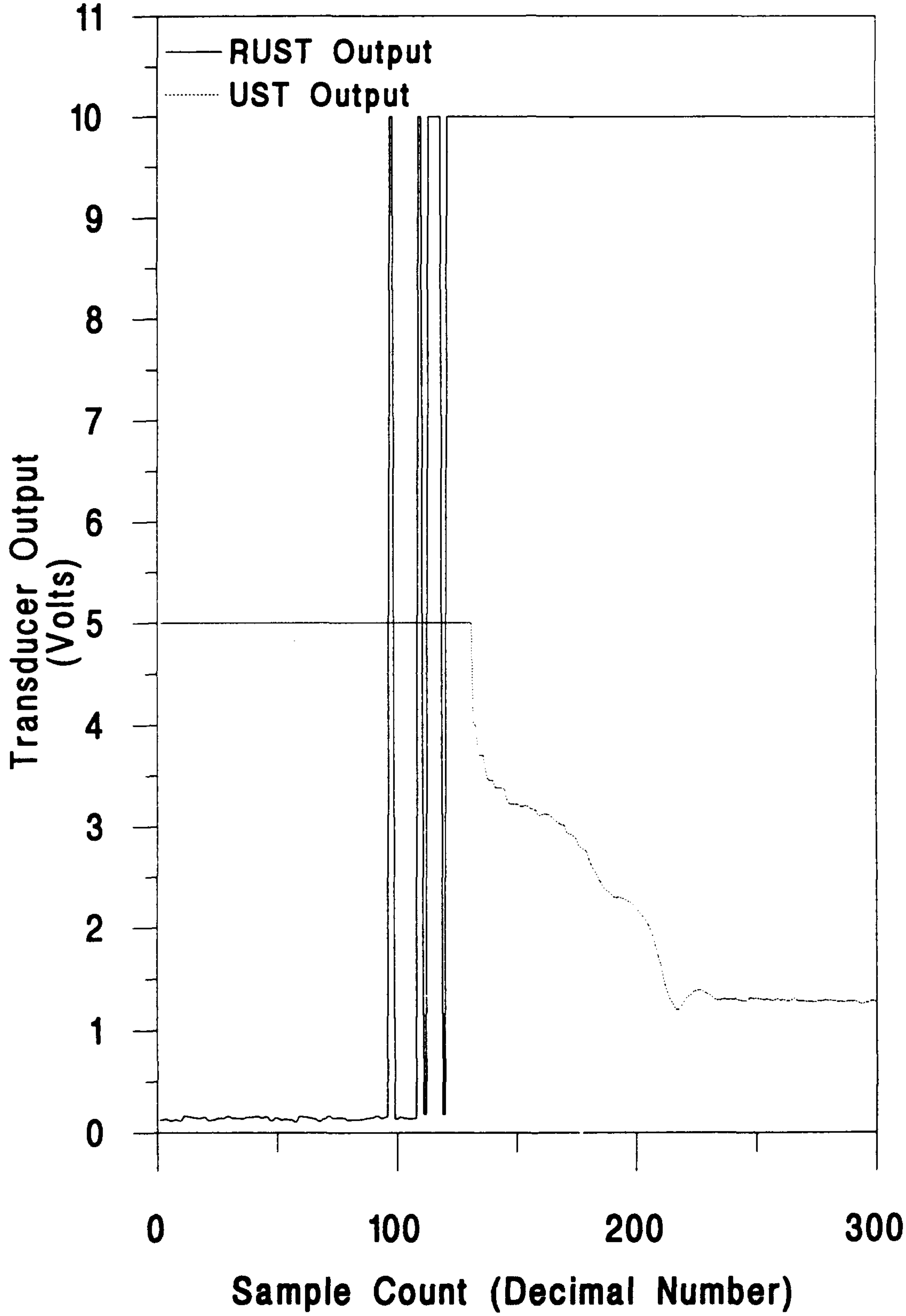


**Figure 8 Output of Tailwheel UST and Controlling RUST During Helicopter Landing**

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